

Mechanisms and potential implications of fragmentation in low-order streams

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Ecologists have long known that stream ecosystems require 4-dimensional connectivity (*sensu* Ward 1989) to sustain natural biodiversity and productivity (Ward and Stanford 1983, Stanford et al. 1996, Olson et al. 2007). That this connectivity is both hydrologically based and significantly altered by human activities is without question (Dynesius and Nilsson 1994, Stanford et al. 1996, Pringle 2001, Bernhardt et al. 2005). The papers in this series describe studies designed to assess or restore hydrologic connectivity in small streams. In a recent review of efficacy of stream restoration, Palmer et al. (2010) reported extremely limited success in increasing benthic biodiversity when restoration efforts were limited to local or proximate spatial scales and advocated a more holistic watershed-scale approach to prioritizing restoration targets (see also Walsh et al. 2005). However, improvement and restoration of flow regimes in ecosystems requires proximate solutions, such as those described herein (i.e., small dam removal and improvements to stream-road crossings), particularly if local 'fixes' can be integrated into holistic watershed-improvement plans.

The papers in this series provide important findings about how ubiquitous instream structures, such as low-head dams and culverts, affect fishes and large-bodied benthic invertebrates and their habitats. Helms et al. (2011) and Gangloff et al. (2011) compared intact, breached, and relict (i.e., entirely removed) mill dams in Alabama (USA). Fish species

richness was lower upstream than downstream of intact dams (Helms et al. 2011), and mussel abundance and richness was higher downstream of intact dams than downstream of partial or relict (flow restored) dams. Both groups reported strong negative effects of breached dams, possibly from changes to instream habitat conditions. Collectively, their results provide important insights about how to implement and prioritize dam removal to improve connectivity within small streams (Pringle 2001, Stanley and Doyle 2003).

Dams are not the only instream structures that alter physical conditions and have the potential to fragment populations. Culverts at road crossings create barriers to the movement of anadromous fishes (Davis and Davis 2011) and crayfishes (Foster and Keller 2011). Davis and Davis (2011) reported elevated catch-per-unit-effort for juvenile salmon upstream of culverts in high-gradient streams (spawning habitats) and downstream of low-gradient, wetland streams (rearing areas) in Alaska. Fish appeared to avoid passing through culverts with high flow velocity. In Michigan streams, elevated flow velocity in culverts limited upstream movement of several crayfish species, and high-flow conditions favored upstream movement of nonindigenous species over native taxa (Foster and Keller 2011). It appeared that restoration efforts could improve fish passage, but culvert restoration projects should be designed individually to achieve sufficiently low-velocity thresholds to facilitate upstream passage by crawling invertebrates or other less-mobile biota.

Our understanding of the ecological implications of instream barriers is growing, but key questions

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remain unanswered. Research is needed to characterize the effects of barriers on diverse stream biota, such as aquatic insects and microbiota in biofilms. Comprehensive studies incorporating multiple taxa and trait-based approaches (e.g., Statzner and Bêche 2010, Walters 2011) hold great promise for improving our understanding of the severity and spatial dynamics of fragmentation. Large gaps exist in our knowledge of the evolutionary implications of these structures for restricting gene flow, but emerging genomic tools are available to quantify these effects (e.g., Buhay and Crandall 2005, Hughes et al. 2009). Information about the causal pathways by which structures influence biota could be used to create new construction and restoration standards designed to protect the biological integrity of stream ecosystems.

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